Voice Characteristics of Young Girl Role in Kunqu Opera

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Abstract: Three electroglottographic parameters, fundamental frequency, contact quotient, and speed quotient were analyzed for two singers of Young girl role in Kunqu Opera. Each singer performed three conditions, singing, stage speech, and reading lyrics. The phonation types adopted in different conditions were explored based on electroglottographic parameters. Fundamental frequency, contact quotient, and speed quotient showed different distributions among conditions. Five phonation types were used in singing and stage speech, which include (1) breathy voice, (2) modal voice with low degree of posterior glottal adduction, (3) modal voice, (4) falsetto, and (5) falsetto with high degree of posterior glottal adduction. The phonation strategies partly showed differences between singers. Different phonation type collocations were employed in singing and stage speech. The relationship between phonation types and pitch was complex. The phonation types actually used were different from and more complex than those in traditional Kunqu Opera singing theory.

Key Words: Young girl role–Singing–Stage speech–Electroglottography–Phonation type.

INTRODUCTION

The Kunqu Opera is a traditional performing art in China and respected as the ancestor of all Chinese operas. The voice timbres of Kunqu Opera singers are supposed to mirror the ages, characters, and identities of the respective roles, which have been described elsewhere.[1] Like in musical theater, two voice conditions are used on stage in Chinese opera. One is singing (S), the other is stage speech (ST), which is also called recitative in Peking Opera.[2] For most roles in Kunqu Opera, the mean fundamental frequency (F0) of ST is significantly higher than that of S,[1] while the opposite is true for the same roles in Peking Opera[2] and in most of other genres of performance, such as musical theater. The object of this research Young girl (YG) role generally performs as a supporting actress and interprets a young and sprightly character. In order to increase the narrative and entertainment of a performance, YG role uses more ST than the leading lady Young woman role. The voice of the YG role is typically described as "wiry", "clear," and "lilting".[3] In the tradition of Kunqu Opera, YG is described as using falsetto register to sing and recite on stage. However, the voice qualities of these two conditions (S and ST) deviate obviously from conversational speech, Western operatic tradition and untrained falsetto, which have been well described in previous research.[4-8] The voice characteristics of YG role exemplify how the voice can be used in dramatic contexts. Some pilot studies show that YG role' ST, S, and conversational speech have different acoustic features.[1,9] The details of the phonation method need further study. The present study focuses on the phonation types (PTs) and investigates the (1) differences among S, ST, and reading lyrics (R for short); (2) differences among pitch ranges; (3) common characteristics between singers. This investigation is from the point of view of electroglottographic (EGG) parameters.

Electroglottography is a noninvasive technique to measure variations in the contact area between the two vocal folds, as a function of time. A small, high-frequency current is passed through two electrodes that are placed on each side of the larynx. Since human tissue is an electrical conductor while air is not, the contacting of the vocal folds will cause variations in the electrical impedance across the larynx. Earlier researches indicate that the rate of change of the EGG signal corresponds to the closing and opening events of the vocal folds.[10-12] Rothenberg[13] identifies certain landmarks and their relation to the glottal airflow pulse during normal voicing. As shown in Figure 1, this model is well-used to speculate the movement and position of the vocal folds during phonation.[14] Clinically meaningful alterations of vocal fold status or behavior also has been reported to result in different geometric characteristics in EGG waveform.[12]

Some EGG parameters have been found relate to PT, such as F0, open quotient (OQ), contact quotient (CoQ), and speed quotient (SQ).[5] The OQ and CoQ are complementary parameters; the former is the ratio between the decontact phase of EGG signal and the fundamental period while the latter is the ratio between the contact phase and the period. A high CoQ is typically associated with a pressed voice while a low CoQ is mostly observed for breathy voice. The definition of SQ is the ratio between decontacting phase and contacting phase in the EGG. In other words, high SQ indicates that the glottal closing is quicker and voice has more high frequency energy.

To identify the contacting and the de-contacting events are essential for the calculation of EGG parameters. Three methods have been suggested and applied in research.[15-19]

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Abbreviations: YG, Young girl role; S, singing; ST, stage speech; PT, phonation type; R, reading lyrics; OQ, open quotient; CoQ, contact quotient; SQ, speed quotient; DEGG, the first derivative of the EGG signal; YG1, YG singer 1; YG2, YG singer 2; WL, the length of the whiskers; YG1_S_n, the *n*th clustering center of YG1's S; MV, modal voice; BV, breathy voice; UDC, the unique degree of the texture of the vocal folds' contacted part; LMV, modal voice with low degree of posterior glottal adduction; F, falsetto; HF, falsetto with high degree of posterior glottal adduction

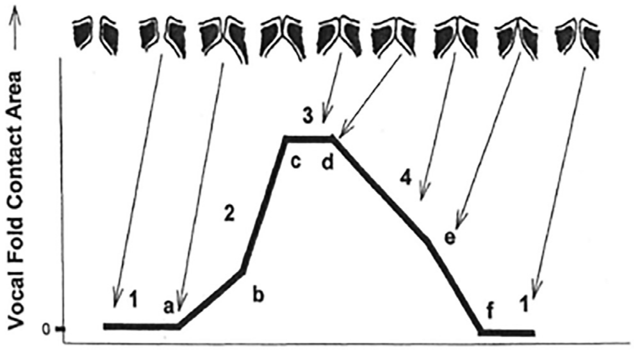

FIGURE 1. A model representing the landmarks in the EGG signal of one cycle of vocal fold vibration. The upper part shows the movement and position of the vocal folds.

Using the first derivative of the EGG signal (DEGG) to delimit contacted phase will encounter some issues. Baer et al.[10] report that it might not apply to the glottal opening in female voices. Henrich et al.[16] observe that if there are multiple peaks, the timing of the glottal event remains undetermined. Rothenberg points out that the weak signals with a large high-frequency noise component is even noisier and therefore not well suited to detect the proper peaks in DEGG signal.[17] In addition, methods using DEGG signal is not suitable for double-peak EGG signal.

METHODS

To explore the characteristics of YG role instead of those of any opera faction, two professional singers from different area were invited as the subjects. The singers were in their middle years (aged 41 and 45 years). Their professional experiences were 22 and 25 years. It is important to note that they were no longer young girls. They were playing a stylized role that typically portrayed young female. The singers were told to sing three songs with different emotion colors of their own choice just as on stage. The songs chosen were similar in emotion color between singers, as the voice timbre was supposed to be analogous in the songs with like emotion color, despite different lyrics. The total duration of the songs was about 18 minutes. The singers also recited a section of ST, which lasted for about 2 minutes. In addition, both singers read, in modal voice, the lyrics of the songs chosen. This reading took about 3 minutes. The language differed from Mandarin Chinese but was identical with what they used in their roles on stage, which actually corresponds to ancient Chinese.

YG singer 1 (YG1), who is a performer of the Kunqu Opera Theater of Jiangsu Province, was recorded in a quiet living room, about 4 m × 5 m × 3 m. Some coarse cloth was stuck on the wall to reduce the reverberation. YG singer 2 (YG2) works at the Northern Kunqu Opera Theater and was recorded in an anechoic room, about 3.6 m × 2.6 m × 2.2 m. A Sony Electret Condenser Microphone, placed off axis on the chest at 15 cm for both singers, was used to record the audio signals. The EGG signal was obtained by an EGG system (Electroglottograph Model 6103; Kay, USA). Those signals were simultaneously recorded and digitized on 16 bits at a sampling frequency of 20 kHz and recorded on dual channel wave files into ML880 PowerLab system. The equivalent sound levels for R, S, and ST were 73, 86, 90 dB for YG1 and 83, 89, 93 dB for YG2.

The EGG signals were analyzed using VoiceLab 1.0.[20] The contacting and the de-contacting events were approximated using the commonly used 35% of the EGG amplitude criterion,[21] which is better than using the first derivative of the EGG signal for abnormal signals. Three parameters were calculated: (1) F0; (2) CoQ; and (3) SQ. Statistical analyses were completed using SPSS 18. The distributions of EGG parameters were compared by a Mann-Whitney *U* test.

As reported, the voice timbres varied a lot in YG role's S.[9] In the tradition training of Kunqu Opera, the phonation methods were grouped into three categories, modal voice, falsetto, and the mixture of both. For YG role, the voice timbre was different in low pitch range versus high pitch range. Thus, variant PTs, which corresponding to various combinations of F0, CoQ, and SQ, were hypothesized to be used in different pitch range. The typical parameter combination for a PT could be located by clustering analysis. Each of three EGG parameters was converted to *z*-score for their different dimensions. A *k*-means method was adopted since the number of clustering and the initial cluster centers could be set. Each parameter was supposed to have a large center and a small one. Therefore, eight centers will lie in the three-dimensional space by F0, CoQ, and SQ. The initial cluster centers were set manually to make the final cluster centers more even. In the initial center, each normalized parameter was set at −0.5 or 0.5. Based on the hypothesis, if there were different PTs, the centers would be dispersive. On the other hand, the centers would coincide or closed to each other.

RESULTS

The distributions of F0 for different conditions of each singer are listed in Figure 2. F0 was transformed into semitones. For both singers, the median of F0 was lowest in R and highest in ST ($P < 0.05$). From the distance between the first and third quartile locations (distribution width of core data, DWCD), the F0 of ST showed a more concentrated distribution compared with that of S and R. The distribution of ST overlapped with that of S, whereas not with the distribution of R.

Comparing the two singers, the CoQ has some commonality but some differences as well (Figure 3). For both singers, ST showed a larger median of CoQ than S ($P < 0.05$). Based on DWCD, the CoQ distribution of S was wider than that of R. For singer YG1, ST showed most concentrated distribution in three conditions, whereas the opposite was true for YG2. With respect to the same condition, ST showed similar DWCD between singers, but S and R did not. If we regard the length of

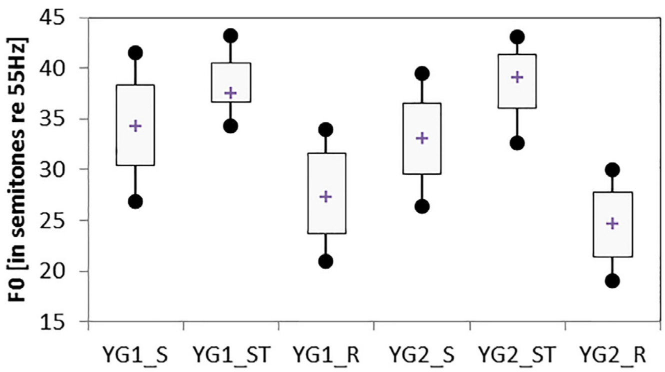

FIGURE 2. Box plot of F0. Crosses inside boxes represent the medians. The box represents the value between the first and third quartile locations. The ends of whiskers represent the value at 10th percentile and 90th percentile. The horizontal axis labels are acronyms of the singers and conditions.

the whiskers (WL) as the reflection of the phonation diversity, for both singers, S showed the greatest CoQ diversity and R showed the least.

Figure 4 illustrates the distributions of SQ for the different singers and conditions. The median SQ was lowest in ST and highest in R ($P < 0.05$). From the point of view of DWCD, for both singers, ST showed most concentrated distribution and R showed the widest. In regard to the same condition, YG1 presented larger DWCD than YG2. As for the phonation diversity, which was reflected by WL, S showed the greater SQ diversity than ST for both singers. However, the relationships between R and the other two conditions are opposite between singers.

To determine the phonation types used by YG role, we have to take all three EGG parameters into consideration. Table 1 illustrated the cluster centers of EGG parameters, the percentage of data around the center and corresponding phonation types for S and ST of two YG singers. A combination of the singer, the condition and the number of the clustering center, such as "YG1_S_1", was used to refer to each clustering center.

As shown in Table 1, the strategies used by two YG singers were somewhat different in S. YG1_S_1 showed a similar F0, CoQ, and SQ to the EGG parameters of YG1's R, thus its PT is modal voice (MV). MV was assumed as the

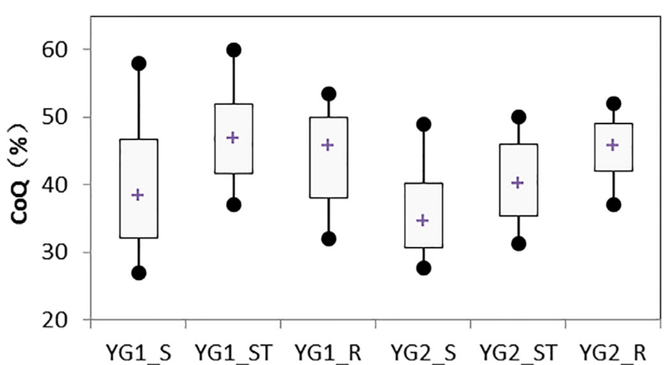

FIGURE 3. Box plot of CoQ.

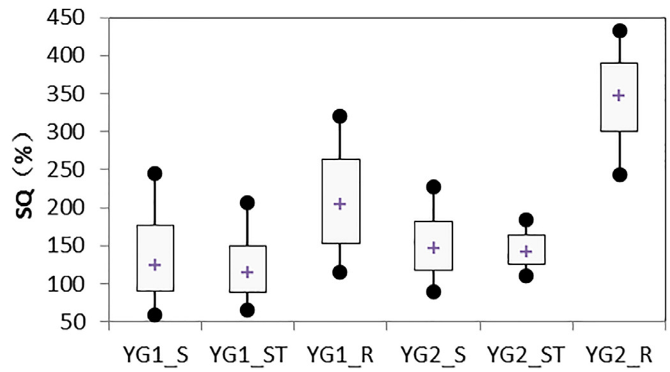

FIGURE 4. Box plot of SQ.

neutral phonation state. The other PTs were determined based on the relationships between their EGG parameters and MV's EGG parameters. For EGG signal that showed a single peak, smaller CoQ stood for more leakage from the glottis, while it was not true for EGG signal that showed double peaks. For SQ, it is related to the texture of vocal fold, the more unique the texture (such as in falsetto, the vocal folds is tense and the difference between the hardness of the cover and the body is smaller) is, the more SQ close to 100. YG1_S_2 and YG1_S_3 showed smaller CoQ than MV and SQ larger than 100, thus they were classified as breathy voice (BV). The unique degree of the texture of the vocal folds' contacted part (UDC) was larger for YG1_S_3 than for YG1_S_2. The CoQ of YG1_S_6 was much larger than that of MV since the EGG signal showed double peaks (see Figure 5A). Based on the high-speed motion pictures of breathy voice,[22] the anterior and posterior glottal area reached the maximum at different instants of time, which suggested that the anterior and posterior parts of the vocal folds vibrated relatively independently. Furthermore, obvious mucosal wave was observed in the high-speed motion pictures. Thus, YG1_S_6 was classified as BV. The left blunt peak was mainly caused by the contact of the anterior part of the vocal folds and the right keen peak was caused by the contact of the posterior part, especially the soft cover of the vocal folds. YG1_S_4 (see Figure 5B) showed a little smaller CoQ than that of MV and similar SQ as BV (YG1_S_3). It showed a series of special characteristics: (1) CoQ implied that the degree of glottis adduction was between that of BV and MV; (2) the smooth peak suggested that the hardness of the vocal fold cover was similar to MV but not to BV; (3) compared with MV, the more triangular de-contacting phase may be caused by a larger phase angle between upper and lower portions of the folds.[12] This kind of phonation type made the transition between MV and BV more natural. Since the timbre differed from both BV and MV, it was described as modal voice with low degree of posterior glottal adduction (LMV). Besides, the proportion of LMV decreased with the rising of pitch. YG1_S_5 and YG1_S_7 showed smaller CoQ than MV and SQ closed to 100%, thus they were classified as falsetto (F). YG1_S_7 (see Figure 5C), which showed higher F0 and larger CoQ than YG1_S_5 and a small hump in the de-contact phase,

TABLE 1.
F0, CoQ, and SQ for each clustering center, the percentage of data around the center and its corresponding phonation type used by two YG singers in two conditions

Singer and Condition	No.	F0/Semi	CoQ/%	SQ/%	Percentage	PT
YG1_S	1	29	48	290	9	MV
	2	29	38	212	14	BV
	3	31	28	146	16	BV
	4	33	45	155	5	LMV
	5	35	31	115	17	F
	6	38	62	53	10	BV
	7	39	38	103	19	F
	8	43	48	84	11	HF
YG2_S	1	27	37	249	9	BV
	2	28	32	183	15	BV
	3	31	29	136	23	F
	4	33	51	243	4	MV
	5	34	39	173	13	BV
	6	37	33	126	21	F
	7	37	59	52	5	BV
	8	41	42	114	11	HF
YG1_ST	1	33	57	283	7	BV
	2	36	47	177	14	LMV
	3	38	36	127	15	BV
	4	40	41	109	17	F
	5	41	64	68	6	BV
	6	43	54	71	8	BV
	7	43	47	107	17	HF
	8	46	49	105	16	HF
YG2_ST	1	34	36	172	12	BV
	2	34	51	273	2	MV
	3	36	32	129	17	F
	4	38	46	184	10	LMV
	5	39	41	151	17	BV
	6	41	37	120	16	F
	7	42	49	154	13	LMV
	8	43	46	122	14	HF

was considered to have higher degree of posterior glottal adduction[23] than YG1_S_5. YG1_S_8 showed same CoQ as MV and SQ smaller than 100% since the peak was in the right part of the contact phase (see Figure 5D). Based on the geometric characteristics in these EGG waveforms,[12] it might be caused by combine action of the convergence in glottis and special vertical phasing of vocal fold. Thus, the PT of YG1_S_8 was named as falsetto with high degree of posterior glottal adduction (HF). From YG1_S_5 to YG1_S_7, and then to YG1_S_8, CoQ increased and SQ decreased, the posterior glottal adduction degree increased.

The PTs of YG2 were similar to YG1s. YG2_S_4 showed a similar CoQ, SQ and a little higher F0 compared with the EGG parameters of YG2's R, thus its PT is MV. YG2 also employed BV (YG2_S_1, 2, 5, and 7), F (YG2_S_3 and 6), and HF (YG2_S_8) in her singing. The waveforms of BV varied a lot. There were also single-peak waveform (YG2_S_1, 2, and 5) and double-peak waveform

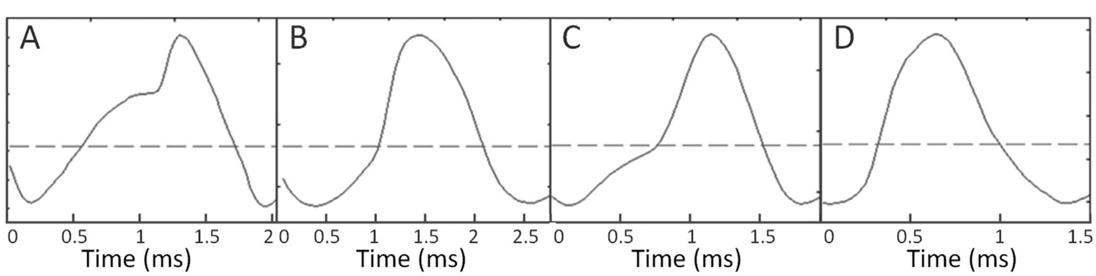

FIGURE 5. Four kinds of EGG waveforms.

(YG2_S_7). The proportion of double-peak waveform was smaller than that of YG1.

The PTs used were slightly different between singers in ST and differed from the phonation types in S. YG1 did not use MV in her ST. Instead, more percentage of LMV (YG1_ST_2), compared with in S, was adopted to make ST sounded different with R. BV (YG1_ST_1, 3, 5, and 6) and F (YG1_ST_4) and HF (YG1_ST_7 and 8) were used, which was consistent with her S. The states of vocal folds were flexible. The covers could be very soft to produce BV (YG1_ST_1, 5, and 6); they could be hard as well to make HF.

YG2 adopted BV (YG2_ST_1 and 5), F (YG2_ST_3 and 6), LMV (YG2_ST_4 and 7), HF (YG2_ST_8), and a few MV (YG2_ST_2). Compared with the PTs in S, the parameters of ST displayed that (1) LMV was largely used instead of BV; (2) the hardness of cover in BV increased and the degree of posterior glottal adduction of HF became higher. These strategies made the voice timbre sound brighter and coherent while pitch changed.

Taken together, BV was used in low and middle pitch range while HF was used in high pitch range. The other phonation types, such as MV, LMV, and F, diversified the voice and made the voice timbre coherent in the entire pitch range. BV, LMV, and HF were also adopted in different proportion by Young woman role in Kunqu Opera,[24] whose voice is more serious and mature and acts a female role a little older than YG. Based on the commonness of two YG singers, the PTs used in middle pitch range were similar between S and ST, while ST adopted more abundant PTs in high pitch range. The relationship between PTs and pitch was not one-to-one correspondence. BV, LMV, and F could occur in more than one pitch range.

DISCUSSION

There were some considerations for the selection of the subjects and their recording materials. First, it is not true for a singing art that the more common points between singers the better. It is easier to find the common characters from the voices of students who were learning Kunqu Opera, than from the voices of famous singers, since the former modeled their voices after a same teacher. But the results may be short of explanation power. On the one hand, their singing skills are developing. On the other hand, part of the common points between their voices may be the characteristics of their teacher or of their opera faction (there are different singing factions in Kunqu Opera). The purpose of this research is not to show the characteristics of YG role in one faction. Thus, the singers' different backgrounds are requisite. In contrast, the subjects we chose are more appropriate. Both singers are national secondary actors (almost the highest level for a supporting character). Long time performance experience made their voice timbres stable and be a clear reflection of YG role. Besides the similarities, each professional Kunqu Opera singer blended a lot of personal characteristics in her voice to make herself a unique singer, a part of which were inherited from her faction and the other part were created by herself. Different singing styles could be perceived as the same role, there must be some substantive characteristics. Thus, the common points between distinctive singers were more likely to be the essential characteristics of a role. Second, the emotion color of the song was the control condition while choosing the songs. The emotion color of the song may influence the voice timbre and the pitch range. Thus, songs with different emotion color were chosen. Because not all the operas which the singers played frequently were same, the two singers chose one same song and two different songs each, which showed similar emotion colors between singers. Since this research analyzed the parameters of EGG signals, which are almost unaffected by words, different songs had little effect on the results. In a word, the analyses based on the voice materials of two professional YG singers are persuasive.

The vertical laryngeal position would influence the EGG values. First, the up-and-down movement of the larynx generated a low-frequency noise, which was well filtered out by off-line data-processing. Its effects on CoQ and SQ were small. Second, the movement of larynx made the amplitude of EGG unreliable. EGG signals reflect the impedance change of the tissues around the glottis and provide information on changes in contact between the vibrating tissues, such as the vocal fold and ventricular folds. Theoretically, the amplitude of EGG is proportional to the relative contact area. But meanwhile, the more distance between the vibration part and the EGG electrodes, the weaker the signal. It turned the amplitude into a trustless parameter. Third, the mismatch of EGG electrodes and larynx reduced the signal-to-noise ratio. While analyzing phonations with incomplete glottal closure having a low EGG signal-to-noise ratio, the relationship between CoQ and closed quotient extracted from other signal is different,[25] so that the physiological signification of CoQ needs a careful analysis. Fourth, the vertical laryngeal position impacted on the shape of EGG signal. The vocal fold is three-dimensional, different parts of it vibrate separately, which is better simulated by ribbon model.[26] When more than one part vibrated alternately, the relative position of larynx and EGG electrodes influenced the signal shapes, such as double-peak EGG signal, which was caused by independent vibrations of anterior and posterior parts of the vocal folds. In YG's BV, single-peak and double-peak EGG signals occur in succession, which was caused by the movement of larynx.

YG role used BV, LMV, MV, F, and HF both in S and ST. The degree of adduction and the hardness of the vocal fold cover were different between PTs, as shown in Figure 6. The horizontal axis was the hardness of the vocal fold cover and the vertical axis the degree of the glottis adduction. The number only represented the sequence. From BV to HF, the vocal folds became stiffer and the space between them decreased gradually until extinction. HF can be produced with a high degree of posterior glottal adduction,[23] which

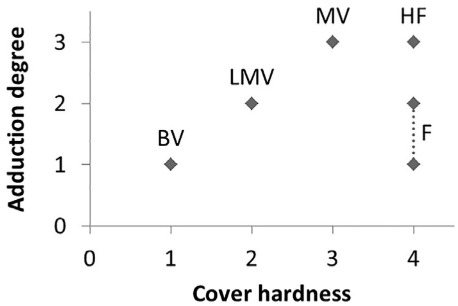

FIGURE 6. The state of the vocal folds in different PTs.

resulted in full glottal closure, as well as MV. However, the stiffness was larger for HF, as well as for F.

Comparing the data shown in Figure 6 and Table 1, the auditory effects of YG role's S and ST were formed by diverse patterns of PTs. The singers altered the vibration methods in their proper pitch range. Thus, "falsetto" was not enough to describe the voice of YG role. The state of the vocal folds in low pitch was distinct from that in high pitch: low degree of glottis adduction and cover hardness in low pitch voice and the opposite in high pitch voice. There was no constant pitch range to switch from one PT to another. However, the relationship between PTs and pitch was complex. It may depend on the emotion of the lyrics. In addition, BV, LMV, F, and HF made the voice timbre of YG role unique. First, the glottis was not completely closed while producing BV and LMV, which resulted in glottal leakage and enable the artistic voice to sound laxer than MV. Second, to produce HF, the degree of posterior glottal adduction should be high. This action effectively increased the subglottal pressure and created a resounding voice. Third, F avoided the abrupt transition of these two kinds of sounds.

Both commonness and individuality could be observed in two YG singers. The PTs showed more similarities in high pitch range than in low, which could be relevant to personal vocal condition. As shown in Figures 2 and 4, for YG1, the pitch of R was high and the pitch range overlapped with that of S. Besides, her SQ was similar in S and R, which implied that her speech voice was closed to her singing voice. On the other hand, YG2 showed a low pitch range and distinct SQ range between R and the other conditions. Thus, it can be seen that the speech voice of YG2 was unfit for portraying YG role, especially in low pitch range. As the pitch went up, the difference between MV and other PTs enlarged and the influence of vocal condition reduced.

CONCLUSION

This study explored the PTs used by YG role in Kunqu Opera based on EGG parameters. The results showed that it is inaccurate to describe YG role's voice in a traditional term "falsetto", since the distributions of F0, CoQ, and SQ were significantly different between S and ST. The auditory effects of YG role's S and ST were formed by complicated patterns of PTs. Besides, the phonation strategies were relevant to singer's vocal condition.

In S and ST, five kinds of PTs were adopted by YG role: BV, LMV, MV, F, and HF. The PTs were not identical in S and ST. The relationship between PTs and pitch was complex. Some PTs could occur in different pitch range. In high pitch range, the PTs showed more similarities between two YG singers than in low pitch range.

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